UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE SAN JACINTO-SAN VICENTE TURNOUT AND METERING STRUCTURE SAN DIEGO AQUEDUCT PROJECT--CALIFORNIA

Hydraulic Laboratory Report No. Hyd-365

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

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Laboratory Report No. Hyd-365
Hydraulic Laboratory Section
Written by: W. P. Simmons, Jr.
Checked and
Reviewed by: W. C. Case
J. W. Ball

Subject: Hydraulic model studies of the San Jacinto-San Vicente Turnout and Metering Structure--San Diego Aqueduct Project, California

PURPOSE

To study the flow distribution, operating characteristics, and head losses in the turnout and metering structure, and to make any changes needed to insure satisfactory operation.

CONCLUSIONS

1. The flow distribution within the turnout structure (Figures 4 and 5) is satisfactory. The slow current which moves along the measuring weir during weir operation should not interfere with the flow measurements or with field calibration of the weir. Changes in openings of the plug valves in the venturi meter throats do not greatly affect the flow distribution in the downstream compartment. Any splashing which may occur in the downstream compartment of the structure will be confined by a cover on the compartment.

2. The various components of the structure operate as designed in controlling and measuring the flow of water. Considerable time must be allowed for the system to stabilize whenever flow conditions are altered because the water levels respond slowly.

3. The head lost when the water leaves the conduit barrels and enters the turnout structure is reduced by expanding transitions in the conduit barrels (Figures 4 and 5). The loss is approximately $0.28 \frac{V^2}{2g}$ for the 48-inch and $0.38 \frac{V^2}{2g}$ for the 54-inch transitions.

4. The opening from the upstream compartment to the weir pool (Figure 4) is adequate for all expected discharges.

5. The losses through the 24-inch pipe line and venturi meter (Figure 5) are not important in the over-all operation of the structure and were not determined.

6. The over-all loss through the preliminary arrangement of 60-inch pipe line and venturi meter (Figure 6) was excessive. Most of the loss occurred in the 15° diffusing cone. The rate of cone expansion was too great to permit an efficient diffusing action when the cone discharged into the open pool in the downstream compartment. As a result nearly the full velocity head in the meter throat was lost.

7. A 3-diameter length of straight pipe between the 15° cone and the downstream compartment, or a 5° cone discharging directly into the compartment, enables sufficient diffusion and recovery of velocity head to reduce the loss to an acceptable value.

8. The loss was high in the original long 36-inch-diameter throat of the 60-inch meter (Figure 6). The long throat contained a plug valve, two sleeve-type couplings, and several feet of pipe. The loss can be reduced by shortening the pipe as much as possible.

9. The loss through the final design 60-inch venturi meter line using the 5° diffusing cone and the shortened throat (Figure 5) was low enough to permit the passage of the maximum 170 cfs flow at the limited head differential available.

10. The loss when the water leaves the downstream compartment and re-enters the aqueduct barrels was approximately $0.40 \frac{V^2}{2g}$, where V is the velocity in either barrel.

11. The total loss through the turnout structure from immediately upstream of the inlet transitions to 3 diameters downstream of the point of re-entry into the aqueduct barrel is approximately 3.60 feet. A total head differential of 4.25 feet is available.

12. The velocity distribution in the throat of the 60-inch venturi meter is sufficiently symmetrical to permit the use of standard meter discharge tables. A field calibration is not required.

RECOMMENDATIONS

1. Use the turnout and metering structure design shown in Figures 4 and 5. This design includes the shortened throat and the 5° diffusion cone on the 60-inch venturi meter, and a cover over the downstream compartment.

2. Make observations in the field to determine the prototype operating conditions and head losses. This can be done when the V-shaped measuring weir is calibrated.

ACKNOWLEDGMENT

The recommended design of the metering and turnout structure is the result of cooperative efforts of the Canals Branch and the Engineering Laboratories Branch of the office of the Chief Engineer in Denver.

INTRODUCTION

The 71-mile-long, 48-inch-diameter, single-barrel aqueduct which connects the San Jacinto and San Vicente Reservoirs was completed in 1947 (Figure 1). This aqueduct, located in southern California, transports water from the Colorado River Aqueduct southward to alleviate the serious water shortage in the San Diego area and at certain intermediate points. The aqueduct is also known as the San Diego Aqueduct. The steadily mounting water demand caused by a large influx of population and by extensive military needs has exceeded the capacity of the single-barrel aqueduct. A second barrel is to be added to raise the over-all capacity to 170 cfs. The design of the second barrel and the other required structures is being done by the Bureau of Reclamation under an arrangement similar to that used for the design of the first barrel. The project is under the direction of the Eleventh Naval District of the United States Navy.

In the original aqueduct a take-off and regulating structure was provided at South Station 49+67 to divert water to the Sweetwater Reservoir (Figures 2 and 3). The structure consisted of two narrow compartments lying side by side and joined by a common wall surmounted with a weir. The flow from the aqueduct entered the first compartment and filled it so that the water flowed over the weir and entered the second compartment. The gate at the end of the first compartment was normally left closed. The rate of flow into the second compartment was measured as the flow passed over the weir. All the water in the second compartment was directed into a continuation of the barrel which carried the flow on downstream. A gate-controlled side outlet, or turnout, was provided at the upstream right end of the first compartment. The necessary head to produce the side delivery was provided by the depth of water in the pool impounded by the weir-topped wall. The flow rate diverted to the side was equal to the difference between the known flow rate entering the structure and the measured flow rate passing over the weir.

The increased capacity provided by the second barrel, and the need for precise flow measurements over a wide range of flows, necessitated a larger and more complex regulating structure than the existing one. The new structure was required to measure flows ranging from zero to 170 cfs with only a small loss in head, and provide a pool with a water surface sufficiently high to produce the required side deliveries. The structure must also be designed so that it can be built without interfering with the continued passage of water through the existing structure.

A tentative design was developed in which the existing structure, with small changes, was incorporated with a large new structure, the latter being arranged so that it could be constructed while flow continued through the aqueduct. The final design of this turnout and metering structure, which incorporated the results of the model studies, is shown in Figures 4 and 5. It is anticipated that after the new part of the structure is finished the old part will be remodeled to make the old and new structure operate as a single unit. In this completed structure the flow from the two aqueduct barrels enters an upstream compartment. An opening in this compartment leads into the section of the old structure which contained the weir. This weir is raised to elevation 772.16 so that no flow will pass over it except in an emergency. Another opening from the upstream compartment leads into a new weir pool which terminates at a weir that is slightly V-shaped with the low point of the "V" at elevation 771.16. The ends of this 30-foot weir are placed 1 foot higher than the weir center. Flows from zero to about 40 cfs can be measured by this weir. An outlet pipe at the right side of the upstream compartment supplements the original side-outlet line that takes water to Sweetwater Reservoir. A 24-inch and 60-inch pipe line extend from the same upstream compartment to another compartment at the downstream end of the structure. These pipe lines contain venturi meters for measuring rates of flow from about 2 to 20 cfs, and from 17 to 170 cfs, respectively. A plug valve is provided in the small-diameter section of each meter line to regulate the flow so that the water surface in the upstream compartment remains high enough to produce the required side deliveries. Any water that passes over the V-shaped measuring weir or over the emergency weir is conducted to the downstream compartment. All the water which enters the downstream compartment re-enters the two aqueduct barrels.

The turnout and metering structure (South Station 49+67) is located at the top of a hill which very nearly approaches the elevation of the hydraulic grade line (Figure 2). The grade line at this point was established at the maximum practicable elevation of 771.16 feet, through the use of 54-inch instead of standard 48-inch pipe in the second aqueduct line. The lower friction loss incurred through the 54-inch pipe left 4.25 feet of head available to compensate for the losses through the metering structure. This limited head required that special attention be given to reducing the losses to a minimum through the structure. Diffuser sections are therefore provided on the exits of the inlet aqueduct lines and on the venturi meters to regain part of the velocity heads. Rounded approaches are provided on the 24- and 60-inch pipe lines and on the aqueduct barrels leading away from the structure to reduce the losses.

It was difficult to foretell by analytical means how the flow would be distributed in the structure at the various operating conditions and how this distribution would affect the head losses. As these questions could best be answered through hydraulic model studies, a testing program was initiated. This report discusses the various models used in the test program and presents the results of these studies.

INVESTIGATION

1:6 Scale Model

A model scale ratio of 1:6 was selected as the best compromise of the desirability of a large model to insure accurate head loss measurements, the available laboratory space and construction cost. The model included the entire turnout and metering structure (both the existing structure and the proposed additions) and the equivalent of 115 feet of the two inlet aqueduct barrels and 73 feet of the two outlet barrels (Figure 6). The turnout and metering structure was constructed inside a large wooden box by means of plywood panels. The joints between panels were sealed with a thick rubber cement and the entire inside of the model was painted with linseed oil to prevent excessive absorption of water which could result in expansion and warping. Some leakage occured through the model joints but these leaks were easily sealed with modeling clay. In general, this means of construction is satisfactory when the model is to be used for only a short time.

The 24- and 60-inch pipe lines and their venturi meter sections were represented by pipe made of lightweight galvanized iron. A 6-inch plug valve was placed in the throat of the large meter so that its effect on the flow distribution in the downstream compartment could be determined for various valve openings. Similarly a 2-inch plug valve was placed in the throat of the small venturi meter. The rounded inlets to the 4- and 6-inch model pipe lines, and to the 8- and 9-inch model aqueduct barrels at the exit of the turnout structure were formed from sheet copper. The transitions connecting the two aqueduct inlet barrels to the turnout and metering structure were made of lightweight galvanized iron.

Piezometers and water level gages were placed at appropriate locations so that the losses incurred through various components of the structure could be measured. Each inlet aqueduct barrel was supplied by a separate pump and the rate of water flow was measured by an orifice-venturi meter in the line. The rate of flow into the structure was controlled by valves in the inlet barrels. The rate of outflow from the structure was controlled by valves in the outlet barrels. The water from the discharge lines returned to the main laboratory reservoir for recirculation.

Operating Characteristics

The operation of the turnout and metering structure is as follows: Water at a known rate of flow enters the structure through the 48- and 54-inch barrels of the aqueduct. A part of this water may be diverted to the right side through the La Mesa-Sweetwater Extension (Figures 2 and 4). The main portion of the water passes on through the structure, where the flow rate is measured, and continues down the

San Jacinto-San Vicente Aqueduct. The amount of water diverted is determined by subtracting the measured rate which continues down the aqueduct from the known inflow rate.

To accomplish its purpose the turnout and metering structure must pass and measure flows ranging from zero to 170 cfs. Flows from zero up to 40 cfs can be measured by the long, nearly flat, V-shaped, sharp-crested weir (Figure 4). This weir will be calibrated in the field so the only tests made in the model were to determine if the weir were placed in such a manner that good measurements were possible. The tests showed that the proposed weir placement (Figure 6) was satisfactory and that the only factor which would affect the weir flow was the slow current which moved parallel to, and near, the weir blade. This current was so slow that it should not cause trouble in the prototype weir measurements. In the final design of the structure the weir was moved upstream and the weir pool shortened (Figure 4). This will probably result in slightly rougher flow in the pool and over the weir.

Flows from 2 to 20 cfs can be measured by the venturi meter in the 24-inch pipe line while flows of 17 to 170 cfs can be measured by the venturi meter in the 60-inch pipe line. During most of the prototype operation the flow rate will be such that the measurements will be made with one of these two meters. The water surface elevation required in the upstream compartment of the structure to produce the side deliveries to the La Mesa-Sweetwater Extention will be maintained by partially closing the plug valve in the throat of the meter being used. This water-surface elevation is nearly as high as the low point in the V-shaped measuring weir (elevation 771.16). If for any reason the rate of side-delivery flow is reduced without a corresponding adjustment on the plug valve, the water in the upstream portion of the structure will rise and flow over the measuring weir. Thus, the weir will operate as a safety spillway while at the same time it will operate as a measuring device. A second weir is provided near the left side of the structure to operate as an emergency overflow whenever the water surface exceeds elevation 772.16 (Figure 5).

The water levels in the model structure responded very slowly to small changes in operating conditions. This requires that care be taken when altering settings in the prototype in order that the final water levels will be those desired.

The water from the described components of the model structure flowed into the downstream compartment without excessive disturbance and entered the aqueduct barrels to continue downstream.

Flow Distribution

Water entered the turnout structure through expanding transitions in the aqueduct barrels. These transitions were effective in reducing the velocity of the water at the transition exits and as a result the flow in the upstream compartment of the structure was satisfactorily smooth. Even with the full 170 cfs flow entering through one barrel, there was no undue disturbance.

Water entered the measuring weir pool through a large opening in the downstream wall of the upstream compartment. The water surface in this pool was calm. However, a slow-moving, counterclockwise (viewed from the top) eddy occurred when no flow passed over the weir. With flow over the weir there was a small but noticeable current along the weir blade. The water which passed over the measuring weir flowed into the downstream compartment of the structure without difficulty. Similarly, no difficulty was encountered when water spilled over the emergency weir at the left of the structure.

The venturi meters in the 60- and 24-inch pipe lines leading from the upstream compartment to the downstream compartment of the structure were provided with diffusers to partially convert the relatively high velocity-head at the meter throats into pressure head at the diffusers exits. This was intended to reduce the amount of head lost when the flow entered the downstream compartment. The preliminary design diffuser for the 60-inch meter (Figure 6) did not produce the required velocity slow-down and the water entered the downstream compartment as a concentrated jet with a velocity nearly equal to the meter throat velocity. Even with these higher-than-anticipated velocities, the flow in the compartment was satisfactory. The diffusers recommended for the prototype structure (Figures 4 and 5) provided good velocity slow-down, thus good flow conditions will prevail in the downstream compartment.

Plug valves were included in the model pipe lines in approximately the same manner as plug valves will be used in the prototype lines so that the effect of partial valve openings on the flow distribution could be determined. The flow in the downstream compartment was not greatly affected by changes in the valve openings.

No cover was needed over the downstream compartment of the model structure because no splashing occured and there was no pronounced tendency for the water to impinge upon and climb the compartment walls. However, splashing and climbing might occur in the prototype structure if the water surface in the downstream compartment of the structure is appreciably lower than anticipated. It is therefore recommended that a cover be placed over this compartment (Figures 4 and 5).

Head Losses Through Structure

Transitions from Aqueduct Conduits to Turnout Structure

The expanding transitions, or diffusers, connecting the aqueduct barrels to the turnout and metering structure were provided to obtain lower entrance velocities to the structure. By partially converting the kinetic energy into pressure head, a lower net energy loss is incurred than if the full pipe line velocity head were lost. The tests showed that the proposed transitions were effective in reducing the loss. Two diametrically opposed piezometers were placed in each barrel 1 pipe diameter upstream from the transition entrance (Figure 6). The loss was taken as the difference between the total head at the piezometer station minus the water-surface elevation in the upstream compartment of the structure. The loss was approximately $0.28 \frac{V^2}{2g}$ in the 48-inch line, and $0.38 \frac{V^2}{2g}$ in the 54-inch line.

Opening into Measuring Weir Pool

No loss measurements were made for this opening. Visual examination indicated that the opening was adequate for any rate of flow possible at this point.

Twenty-four-inch Pipe Line and Venturi Meter Loss

No loss measurements were made for this pipe line and venturi meter because these losses were of little importance compared to those through the 60-inch line and meter. Moreover, any design modications found necessary in the 60-inch line could be applied directly to the 24-inch line.

Sixty-inch Pipe Line and Venturi Meter Loss

The combined flows of both aqueduct conduits (minus any side deliveries) will normally flow through the 60-inch pipe line and venturi meter. It is therefore of the utmost importance that the flow losses through the pipe line and meter be as low as possible. The over-all losses were determined by measuring the elevation difference between the water surfaces in the upstream and downstream compartments of the structure. Prior to taking these measurements the 6-inch plug valve in the venturi throat was replaced by a section of straight pipe so that the continuous passage expected in the prototype plug valve would be represented in the model.

The over-all line loss of $5.15 \frac{V^2}{2g}$ based on the 60-inch pipe was much greater than anticipated and required a head differential of 5.98 feet to pass the required flow of 170 cfs. Only 4.25 feet of differential was available for the entire structure. The tests were extended to determine the source of the excessive loss.

Two diametrically opposed piezometers were placed in the model pipe line 5.5 diameters downstream from the entrance (Figure 6). A second pair of piezometers was placed in the throat of the meter 2.5 throat diameters from the throat entrance. The entrance loss plus the friction loss to the 10-inch meter inlet was

$0.18 \frac{V^2}{2g}$. The loss through the 10- to 6-inch conical reducer, which had abrupt boundary surface changes where the cone joined the 10- and 6-inch pipes; plus the friction loss in the 2.5-diameter length of meter throat; was $1.10 \frac{V^2}{2g}$ based on the 10-inch pipe. The friction loss in the remaining 2.83-diameter length of throat plus the friction and dumping loss for the 6- to 10-inch conical diffusion was $3.87 \frac{V^2}{2g}$ based on the 10-inch pipe. The latter loss was by far the greatest, and it appeared that much of it could be eliminated. The high dumping loss resulted from insufficient diffusion in the 15° cone. As a result a large portion of the relatively high velocity-head at the meter throat was lost.

A review of data on conical diffusers showed that rapidly diverging tubes, even though successfully used within pipe lines, are not suitable for use where they discharge directly into open reservoirs. For discharging into open reservoirs the total included conic angle should not be greater than 5°. Therefor the 15° cone of the 60-inch venturi meter, which discharged directly into the downstream compartment of the turnout structure, could not be an efficient diffuser. The required diffusion could be obtained in two ways: (1) adding a section of straight pipe downstream from the diverging cone, or (2) decreasing the angle of divergence.

Model studies were made using air for the testing medium to determine which of the two methods was more feasible. The various pipe sections were made of light-gage sheet metal. The centrifugal air pump available in the Hydraulic Laboratory was large enough to allow the use of the 1:6 model scale ratio. The rate of air flow was measured by a 6-inch-diameter, sharp-edged, flat-plate orifice mounted on the upstream end of a 9-foot-long, 12-inch-diameter pump inlet pipe. The sections of pipe tested were attached to the 10-inch outlet of the pump by a 62-inch length of 10-inch pipe and by suitable transitions. All piezometric pressures were measured in inches of water by means of U-tubes; each U-tube having one leg open to the atmosphere. Incompressible flow equations were used in all the air test calculations because the flow velocities were kept below 300 feet per second. The air density was determined from the prevailing air temperature and barometric pressure. The air discharged freely from the pipe line into the atmosphere in the same way that water would discharge from a submerged pipe line into a large pool.

<u>Length of pipe required on 15° conical diffuser.</u>

The 15° conical diffuser with a 6-inch diameter inlet and a 10-inch-diameter outlet was connected to the air pump by 24-inch-long, 10- to 6-inch reducer, and a 48-inch-long, 6-inch-diameter pipe (Figure 7A). The velocity profiles on the vertical and horizontal diameters 1/2-inch upstream from the exit of the 6-inch pipe are shown in Figure 8E. The velocity front was slightly distorted with the maximum velocity occurring near the bottom of the pipe on the vertical diameter and near the right side (looking in the direction of the flow) of the pipe on the horizontal diameter. No attempt was made to improve this flow distribution because the head loss data were needed as soon as possible, and because the distribution was sufficiently good to produce reasonable test results.

The total head entering the diffusing cone was obtained by adding the velocity head in the 6-inch pipe line to the static pressure in the 6-inch line 3 inches upstream from the pipe end. The difference between this total head and atmospheric pressure was taken as the loss through the cone. For the condition where the cone discharged directly into the atmosphere the loss was 3.86 $\frac{V^2}{2g}$ based on the 10-inch pipe (Figure 8A). A 2-diameter length of 10-inch pipe attached to the diffuser outlet altered the flow characteristics so that the over-all cone and pipe loss decreased to 2.68 $\frac{V^2}{2g}$. A 3.1-diameter length (this length plus the length of the 15° cone nearly equals the length of a 5° cone) reduced the over-all loss to 2.52 $\frac{V^2}{2g}$. A 5-diameter length (the longest tested) produced an over-all loss of 2.40 $\frac{V^2}{2g}$. Horizontal diameter velocity profiles 1/2-inch upstream from the system exits are shown in Figure 8C. The velocity profile is extremely distorted at the cone exit when there is no pipe downstream. When pipe is added the profile becomes more symmetrical.

From the above and subsequent test data, it was determined that about 3 diameters of pipe would be required downstream from the 15° diffusing cone to obtain losses low enough so that the metering structure could pass the required flow.

<u>5° conical diffuser.</u>

A cone with a 5° total included angle and inlet to outlet ratio of 0.6 is about the same length as a 15° cone of the same inlet to outlet ratio, plus 3.1 diameters of the outlet pipe (Figure 7B). It appeared that there would be less loss through the 5° cone, which does not require downstream piping to obtain diffusion, than through the 15° cone with its pipe line. A 5° cone was therefore made and tests showed the loss through it to be 2.10 $\frac{V^2}{2g}$ based on the 10-inch pipe. An additional test was made with 2 diameters of pipe on the exit of the cone. The loss was reduced to 1.88 $\frac{V^2}{2g}$. The velocity profile on the horizontal and vertical diameters at the exit of the 5° cone with no pipe is shown in Figure 8D.

The lower loss offered by the 5° cone made it more desirable for use than the 15° cone with its necessary piping. Further loss reduction, which could be obtained by adding a short length of pipe downstream from the 5° cone, would serve no useful purpose in this case and would require a longer and more costly structure. The 5° cone without additional pipe was therefore recommended for the exit of the prototype 60-inch venturi meter.

Either a 5° or a 15° cone may be used at the exit of the 24-inch meter, because in either case the cone will discharge into a pipe of appreciable length.

Effect of rounding the junction between the contracting cone and meter throat. In the hydraulic model the loss measured from the meter entrance to the station in the meter throat was higher than anticipated. A possible reason for this was that the 21° converging cone was connected directly to the 6-inch-diameter pipe forming the meter throat, thereby forming a "sharp corner" at the throat entrance (Figure 9A). The converging streamlines of the flow leaving the cone continue to converge in the 6-inch pipe line and form a vena contracta. The eddy losses resulting from the redistribution of this flow to normal flow in the 6-inch line would cause the measured loss to be greater than the loss assumed for a well-shaped converging section. The effect of rounding the junction between the cone and the straight throat section was determined by testing a representative pipe section. The section consisted of a 5-diameter length of 10-inch pipe, a 21° converging cone, a 2-inch-long plaster junction which could be altered, and an 8-diameter length of 6-inch pipe. A ring of four piezometers was placed 2 inches upstream from the cone entrance. No piezometers were used in the throat section. The loss due to the cone and plaster junction was taken as the difference between the total head above the cone, and atmospheric pressure plus a calculated friction loss for the 6-inch pipe. This friction loss was determined by Darcy's formula, $h_1 = f \frac{l}{d} \frac{V^2}{2g}$. The friction factor f was taken as 0.015.

The loss with the sharp corner (Figure 9A) was $0.10 \frac{V^2}{2g}$ based on the 10-inch pipe (Figure 9D). The plaster junction between the cone and throat was then rounded to a 6-inch radius (Figure 9B). The loss was about $0.08 \frac{V^2}{2g}$ (Figure 9D). For a radius of rounding of 10-inch the loss was about $0.05 \frac{V^2}{2g}$ (Figures 9C and 9D). Thus, by generously rounding the junction between the cone and the throat, the head loss through the cone and junction was reduced by about one-half.

Loss in venturi meter with long throat. The throat section of the 60-venturi meter in the turnout and metering structure is longer than in the usual venturi meter because it includes a plug valve, two short sections of pipe and two sleeve-type couplings. The over-all loss of the meter with a long throat was determined by air model tests, and the loss with the long throat was found to be high. The long meter was formed by attaching the 5° cone to the downstream end of the 48-inch-long, 6-inch-diameter pipe which was connected to the 21° converging cone and plaster junction (Figure 7D). A short meter was obtained by placing the 5° cone directly on the plaster junction at the outlet of the contraction cone. The 10-inch radius rounding at the junction was used with both the long and short meters.

The over-all loss for the long meter, measured from 2 inches upstream from the contraction cone to the atmosphere, was 34 percent of the calculated meter differential. Similarly, the over-all loss for the short meter was 12 percent of the calculated meter differential. These values are equivalent to 2.30 $\frac{V^2}{2g}$ and 0.77 $\frac{V^2}{2g}$ respectively, based on the 10-inch pipe.

The loss difference between the long and short meter was greater than could be accounted for by adding the measured loss of the short meter to a calculated loss for the long throat using Darcy's formula and a friction coefficient of 0.015. This coefficient was based upon Reynold's Number, pipe roughness, and the assumption that the flow occured with a fully developed velocity front. Actually the flow leaving the converging cone entered the meter throat with a flat velocity front with high shear forces prevailing in the boundary layer (Reference 1). Table 1 of Reference 1 shows that the effective friction coefficient for this type of flow in the 8-diameter long throat with a rounded entrance is 1.4 times greater than that for flow with a fully developed velocity front. This accounts for part of the higher than expected loss in the long-throat meter. The remainder of the loss might be attributed to the effect of different velocity profiles entering the diffuser cone.

Loss through final meter design. For low meter losses, the meter throat should be made as short as possible. Economically, however, it was desirable to locate the regulating valve in the smallest diameter section of the pipe line. A compromise was reached wherein the valve was retained in the small diameter line, but moved upstream as close to the throat pressure taps as was allowable. A distance of at least 1.5 pipe diameters is required between the pressure taps and the valve to prevent the valve from influencing the meter readings. The small-diameter line was continued downstream from the valve only as far as required by the sleeve-type couplings. The resulting over-all length of the meter throat was 12.5 feet (Figure 5). A new throat section was made for the air model so the over-all loss

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Reference 1--Theory of Flow Through Short Tubes with Smooth and Corrugated Surfaces and with Square-Edged Entrances--G. H. Keulegan of the final meter design could be determined. The loss was 31 percent of the calculated meter differential, or $2.07 \frac{V^2}{2g}$ ($2.07 \frac{V^2}{2g}$ for the prototype based on the 60-inch pipe). It should be noted that this loss value may be slightly high because the prototype meter will have a machined ogee-shaped converging cone and accurately machined and fitted joints. There will be proportionately less loss due to local eddies in the prototype meter than in the model.

Rounded Entrances from Turnout Structure to Aqueduct Barrels.

The entrances to the 48- and 54-inch aqueduct barrels at the downstream end of the structure were rounded to a 1 foot radius (Figures 4 and 5). Tests were made to determine the loss incurred as the water in the downstream compartment entered the pipe lines and flowed to a point about 3 diameters downstream (Figure 6). No provisions were made in the model to measure the flow in each outlet barrel and it was necessary to pass all the flow through one barrel at a time in order to know the flow rate in that barrel. The head loss was taken as the difference between the downstream compartment water surface elevation and the total head at the piezometer stations. The measured loss was $0.48 \frac{V^2}{2g}$ in the 48-inch barrel and $0.36 \frac{V^2}{2g}$ in the 54-inch barrel.

Summation of Losses.

A summation of the losses incurred from a point 1 diameter upstream from the diffusing sections at the inlet of the structure to a point 3 diameters downstream from the structure is presented in Table 1. These losses are for the maximum flow of 170 cfs (72 cfs in the 48-inch barrel and 98 cfs in the 54-inch barrel) with a 5° diffuser at the end of the 60-inch venturi meter and with the flow discharging directly into the downstream compartment of the structure. All the aqueduct flow is assumed to be passing through the 60-inch meter with the plug valve fully opened.

TABLE 1

Components	Loss using 48-inch barrel		Loss using 54-inch barrel	
	Factor	Loss, feet H_2O	Factor	Loss, feet H_2O
Exit, inlet barrels	0.28hv	0.14	0.38hv	0.22
60-inch line to meter	0.18hv	0.21	0.18hv	0.21
60-inch meter & hv	2.07hv	2.40	2.07hv	2.40
Entrance, outlet barrels	0.48hv	0.25	0.36hv	0.21
Outlet barrels, hv	1.00hv	0.51	1.00hv	0.59
Total loss		3.51		3.63

The total loss will be less than the maximum permissible value of 4.25 feet of water.

Shortened Weir Pool Due to 60-inch Pipe Line Changes

The necessity of a longer pipe line downstream from the meter throat to obtain adequate head recovery in the 60-inch line required that either the over-all structure be lengthened or that the upstream elements of the pipe line be shortened. The latter course seemed more feasible because part of the shortening had already been accomplished by moving the valve nearer the taps of the meter throat. The remaining shortening was accomplished by moving the meter upstream so that the upstream meter taps were 5-pipe diameters from the conduit inlet; the minimum distance recommended by meter manufacturers (Figure 5). This change in location necessitated a corresponding change in the location of the meter access pit. The result was that the downstream end of the weir pool was moved upstream so that the pool length was shortened from 39 feet to 31 feet 3 inches (Figures 4 and 6). The length of the measuring weir was left at 30 feet and the weir was moved upstream.

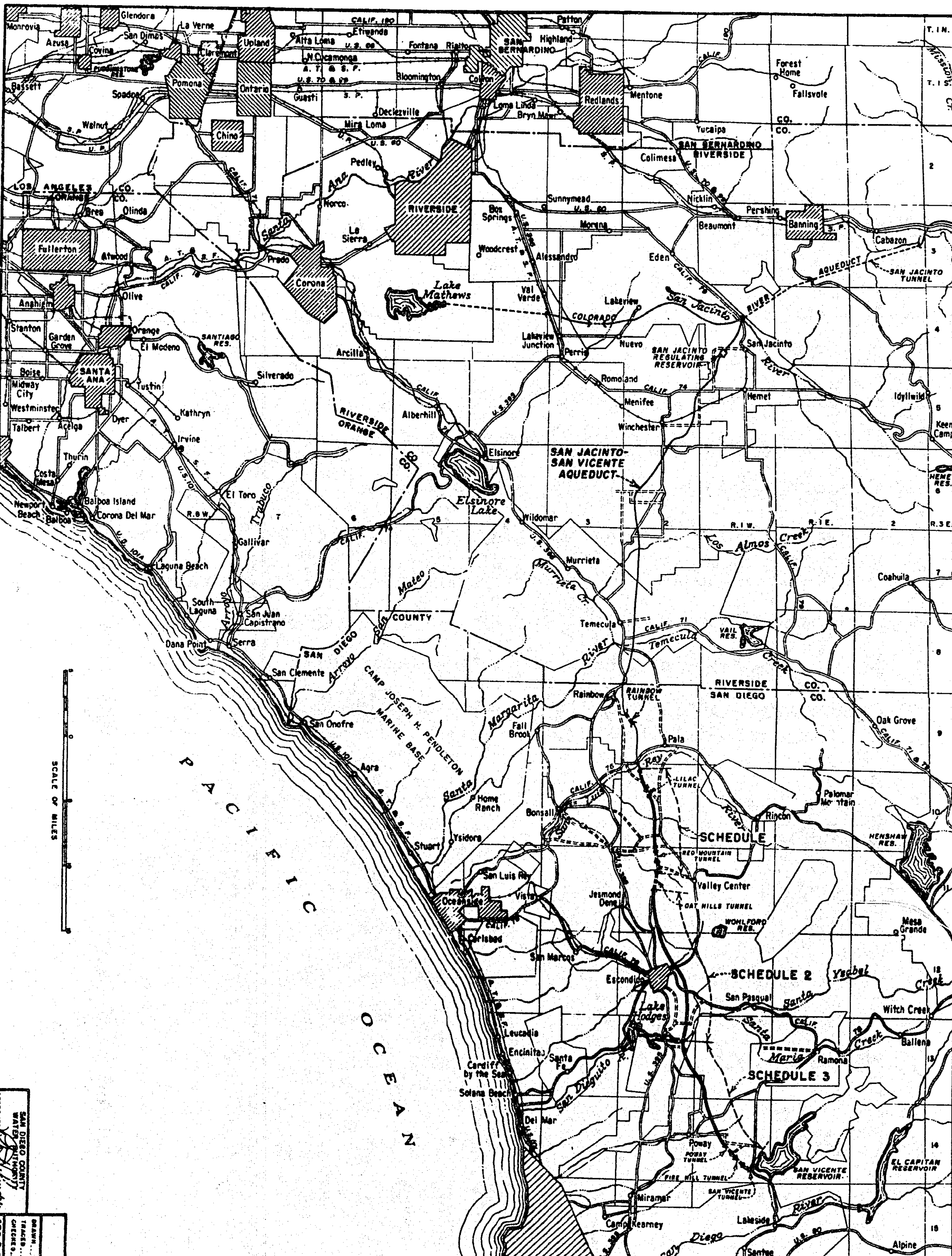
It was believed that the shortening of the weir pool and the change in the weir's location will not materially affect the flow over the weir. In this light, revisions to the model were not justified, and therefore no model tests were made on the shortened pool.

Velocity Distribution in Throat of 60-inch Venturi Meter

The operating characteristics of properly installed venturi meters are well known and tables are available for accurately determining the rates of flow from the measured pressure differentials. For these standard tables to be applicable it is necessary that the flow into and out of the meter measuring sections occurs with approximately symmetrical velocity fronts.

In the turnout and metering structure the flow into the entrance of the 60-inch pipe line is partially confined at the bottom by the floor and at the left side by a sloping wall (Figure 10A and B). This confinement appeared capable of producing a distorted velocity front within the pipe line which would carry through to the meter 5 diameters downstream from the entrance. Any severe distortion may cause inaccuracy of the flow measurements. Velocity profiles were therefore taken on the model along the horizontal and vertical diameters of the meter throat 2 inches downstream from the exit of the converging cone (Figure 10C). Flow entered the turnout structure through the 48-inch aqueduct barrel at a prototype equivalent of 64.3 cfs, and through the 54-inch barrel at prototype rate of 79.1 cfs. The combined equivalent flow of 143.4 cfs all passed through the meter. The velocity profiles are presented in dimensionless plots where the measured velocities are divided by the average cross sectional velocity determined from the discharge and conduit area. The position across the passage is expressed as the ratio of the distance from the wall to the conduit diameter. The distribution was found to be reasonable uniform and symmetrical, thus standard venturi meter tables may be used. A field calibration of the meters does not appear necessary.

Interior - Reclamation - Denver, Colo.



ELEVENTH NAVAL DISTRICT - SAN DIEGO, CALIF.
SAN DIEGO AQUEDUCT PROJECT

SAN JACINTO - SAN VICENTE AQUEDUCT
SECOND PIPE LINE
NORTH STA. 1968+15 TO SOUTH STA. 3426
LOCATION MAP

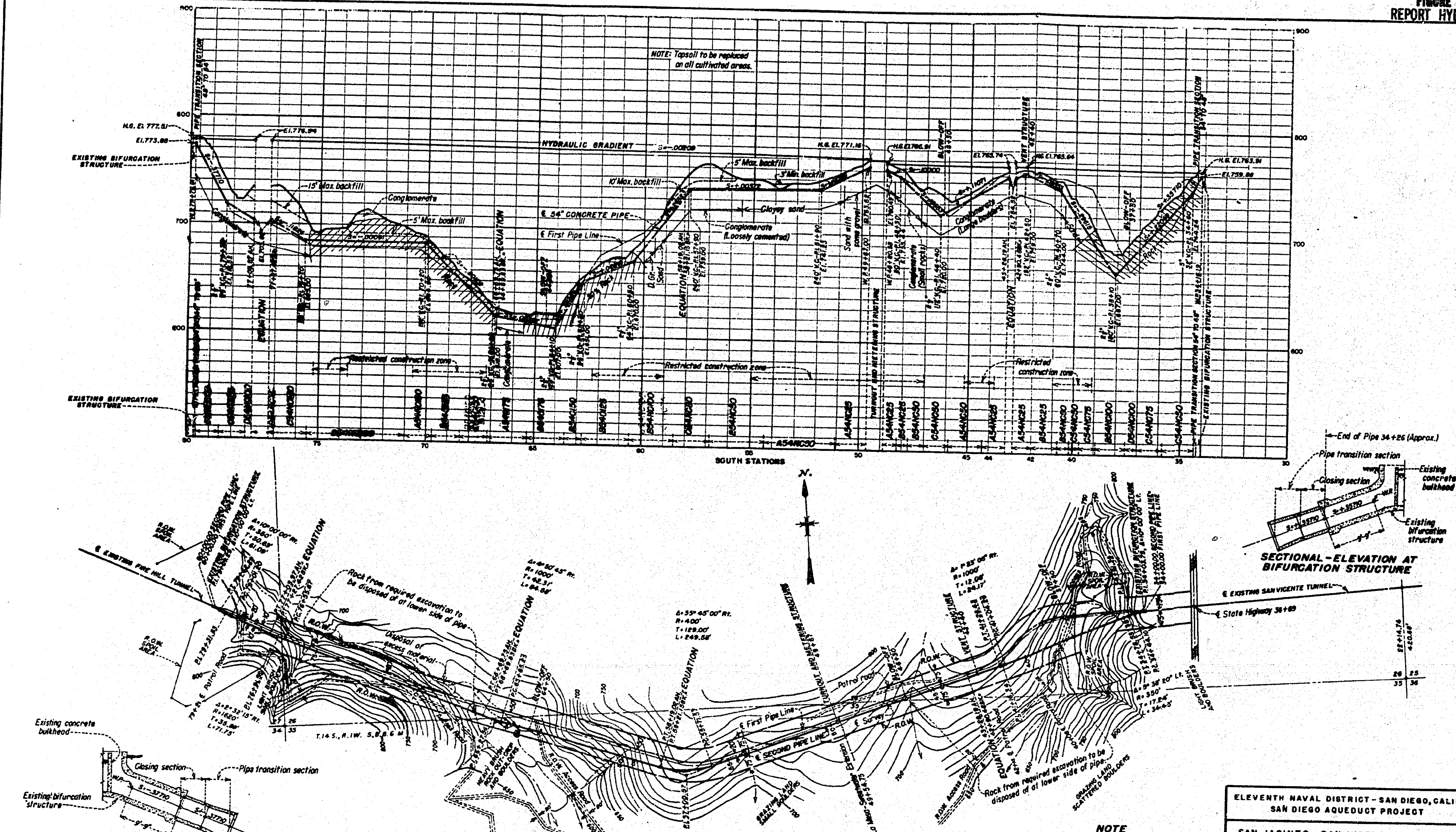
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

DRAWN L.F. SUBMITTED
TRACED B.F.W. RECOMMENDED
CHECKED APPROVED
CHIEF ENGINEER
DENVER, COLO. AUG. 1, 1952
409-D-377

SAN DIEGO COUNTY WATER AUTHORITY
APPROVED

YBD DRAWING NO. 569926
SHEET 1 OF 46
ACCOMPANYING SPECIFICATION NO.
APPROVED PUBLIC WORKS OFFICER

FIGURE 1
REPORT HYD. 365



NOTE
For general notes see Dwg. 409-D-379.

HYDRAULIC PROPERTIES

PIPE	A	V	Q	C_s	r	s
54"	15.90	6.16	98	.37	1.12	.00209
*48"	12.57	5.73	72	.37	1.00	.00209

*Existing first pipe line

SAN DIEGO COUNTY WATER AUTHORITY
APPROVED

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

409-D-404 DENVER, COLO.

ELEVENTH NAVAL DISTRICT - SAN DIEGO, CALIF.
SAN DIEGO AQUEDUCT PROJECT

SAN JACINTO - SAN VICENTE AQUEDUCT
SECOND PIPE LINE

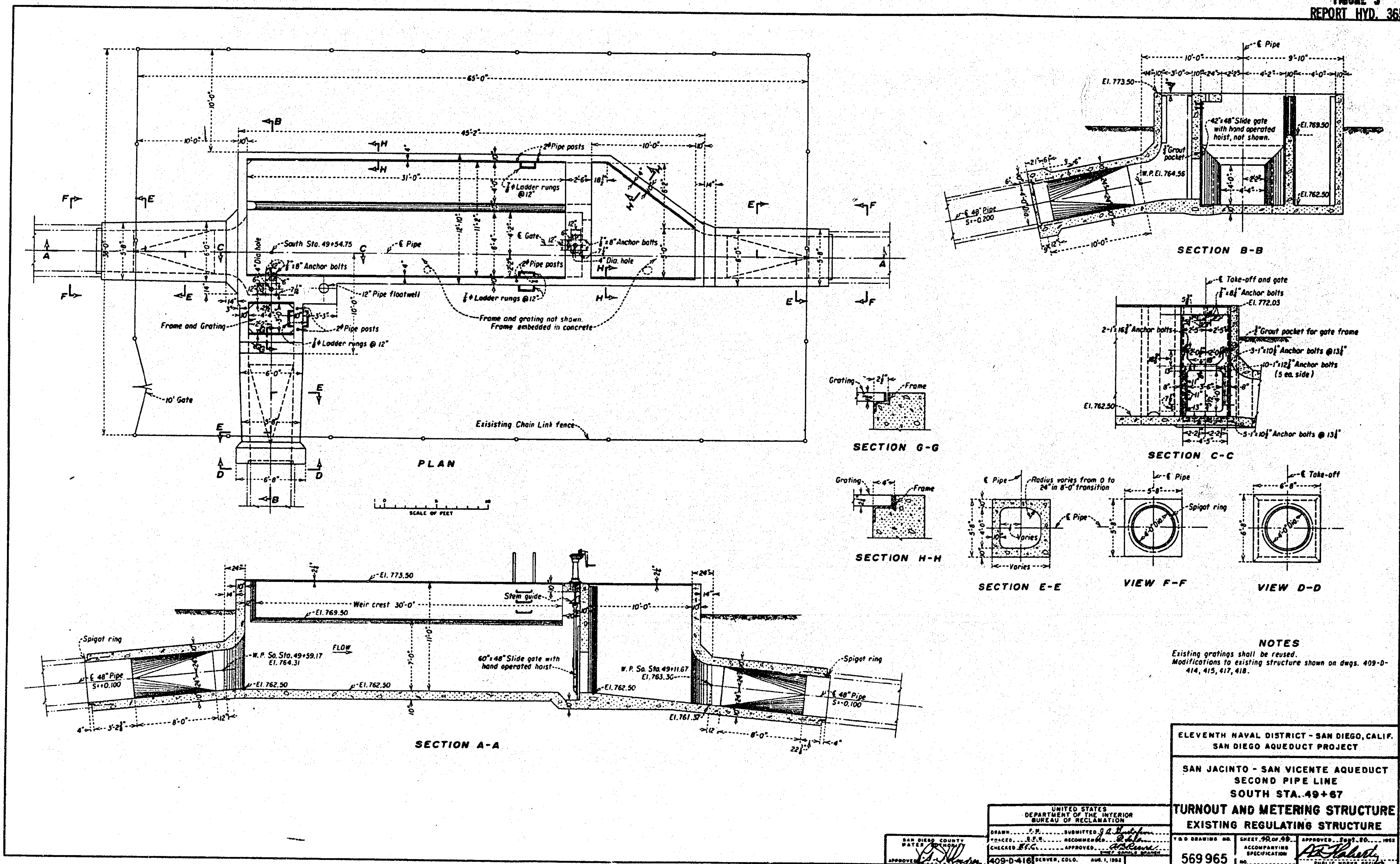
SOUTH STA. 80+00 TO 34+26

PROFILE AND ALINEMENT

Y&D DRAWING NO. 569953

SHEET 20 OF 49
ACCOMPANYING SPECIFICATION NO.

APPROVED Sept. 26 1952
PUBLIC WORKS OFFICER


PLAN
SECTION A-A
SECTION B-B
SECTION C-C
SECTION E-E
SECTION G-G
SECTION H-H
VIEW F-F
VIEW D-D
SCALE OF FEET
Exisisting Chain Link fence
10' Gate
Frame and Grating
Frame and grating not shown.
Frame embedded in concrete
12" Pipe floatwell
South Sta. 49+54.75
60"x48" Slide gate with hand operated hoist
42"x48" Slide gate with hand operated hoist, not shown.
Weir crest 30'-0"
El. 773.50
El. 769.50
El. 762.50
FLOW
Spigot ring
NOTES
Existing gratings shall be reused.
Modifications to existing structure shown on dwgs. 409-D-414, 415, 417, 418.
ELEVENTH NAVAL DISTRICT - SAN DIEGO, CALIF.
SAN DIEGO AQUEDUCT PROJECT
SAN JACINTO - SAN VICENTE AQUEDUCT
SECOND PIPE LINE
SOUTH STA. 49+67
TURNOUT AND METERING STRUCTURE
EXISTING REGULATING STRUCTURE
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SAN DIEGO COUNTY WATER AUTHORITY
409-D-416
DENVER, COLO.
AUG. 1, 1952
569 965

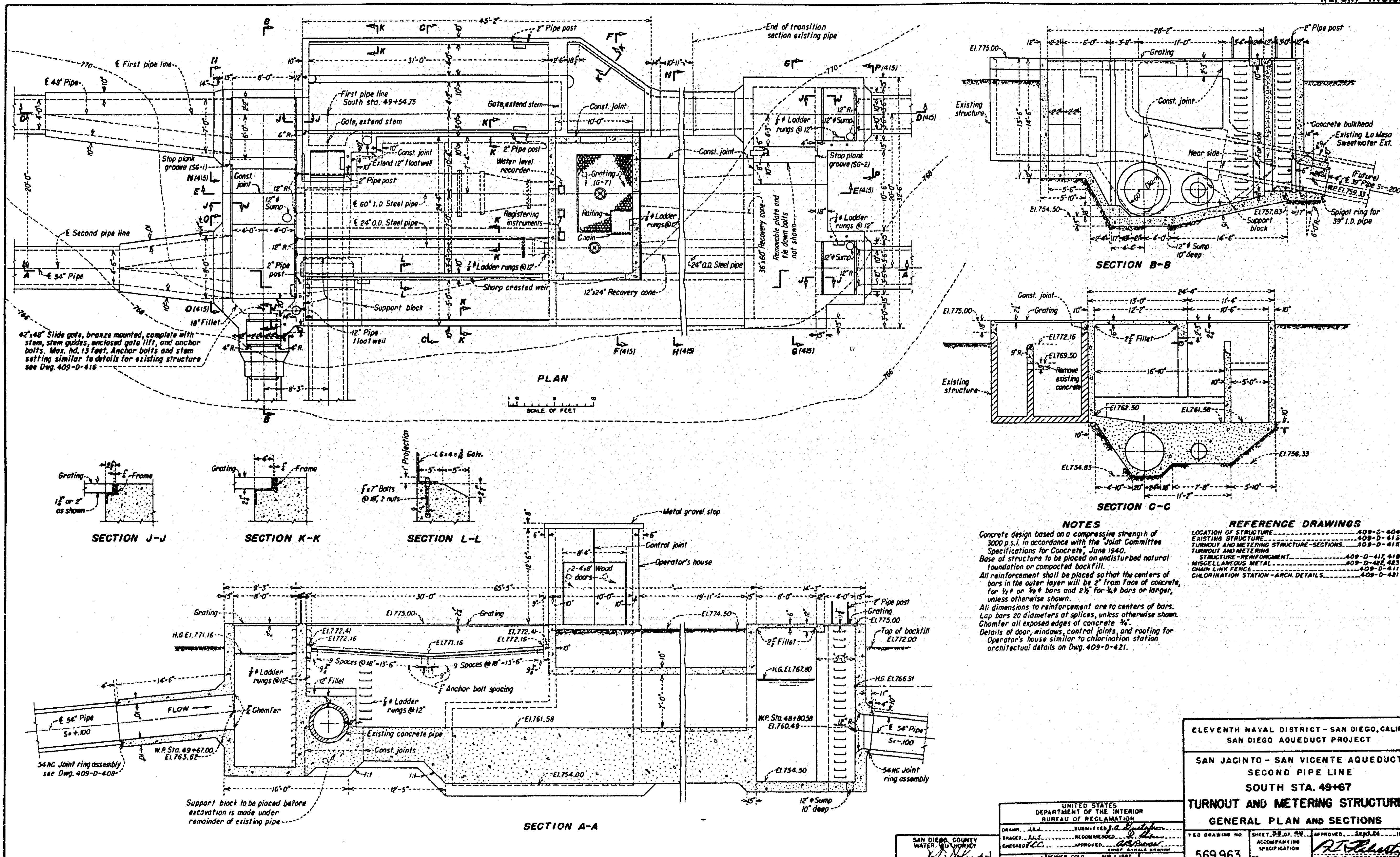
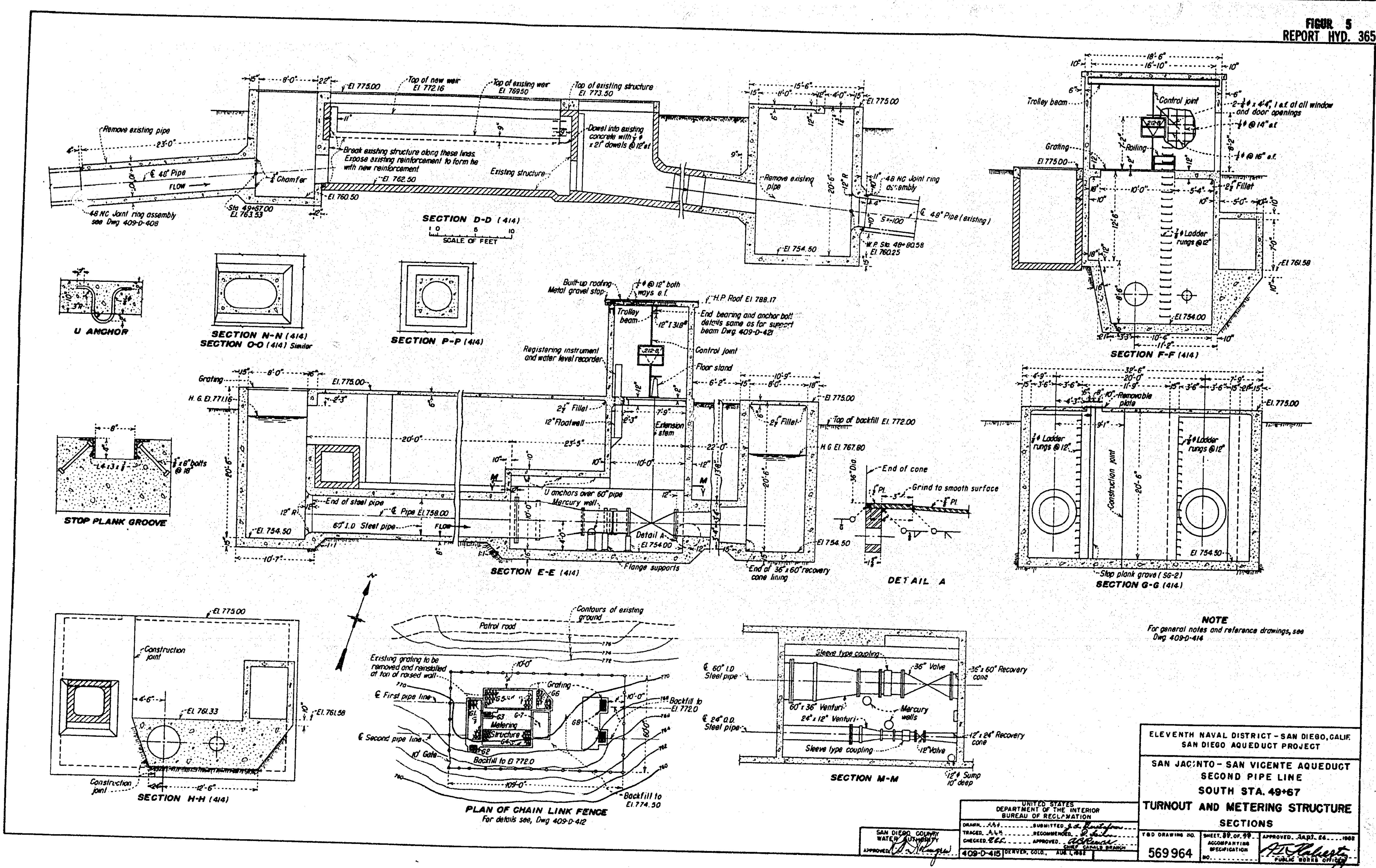
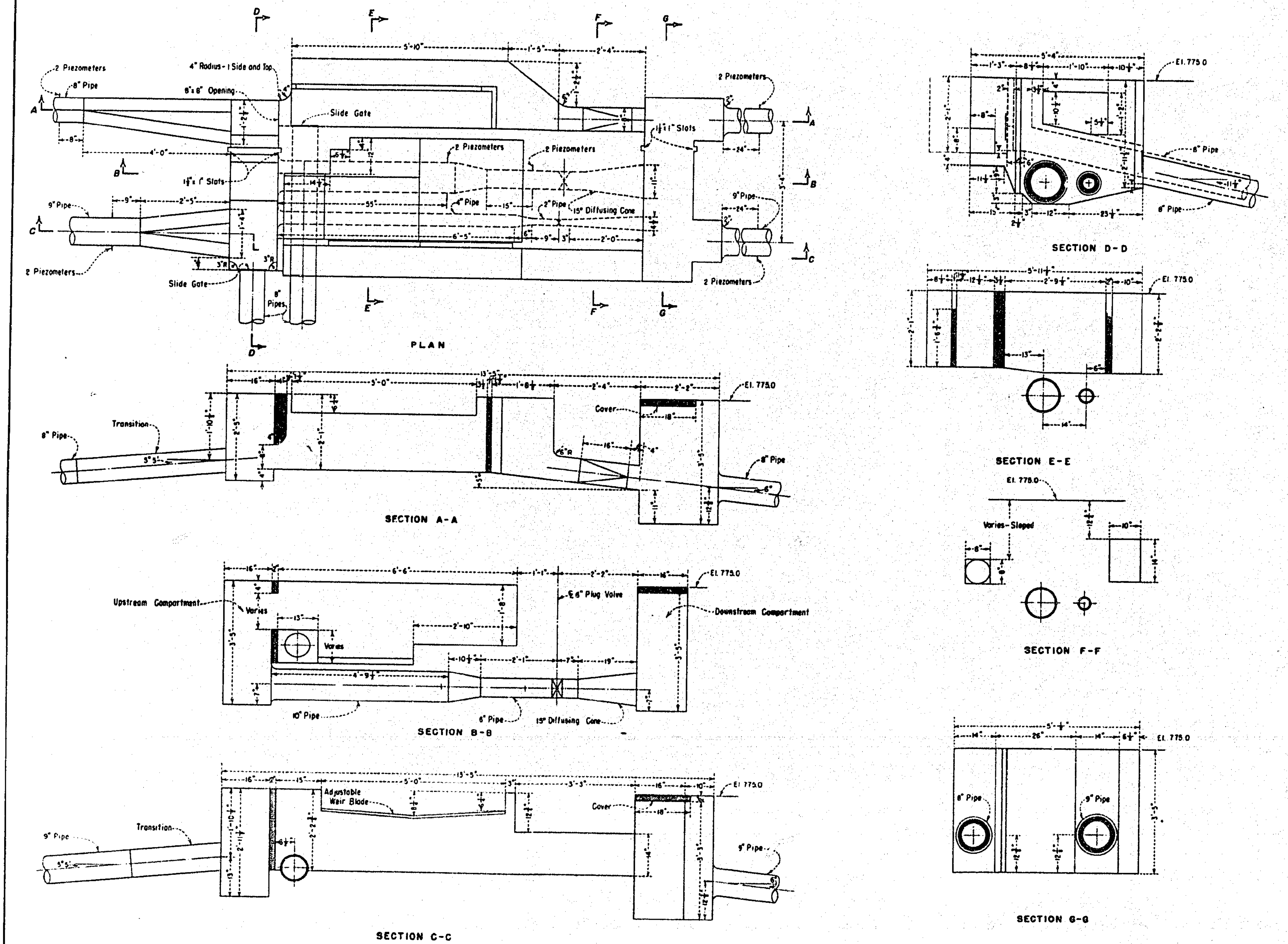

PLAN
SCALE OF FEET
SECTION B-B
SECTION C-C
SECTION J-J
SECTION K-K
SECTION L-L
SECTION A-A
42"x48" Slide gate, bronze mounted, complete with stem, stem guides, enclosed gate lift, and anchor bolts. Max. hd. 13 feet. Anchor bolts and stem setting similar to details for existing structure see Dwg. 409-D-416
First pipe line South sta. 49+54.75
Second pipe line
Sharp crested weir
Support block
Registering instruments
Water level recorder
Operator's house
Metal gravel stop
Support block to be placed before excavation is made under remainder of existing pipe
NOTES
Concrete design based on a compressive strength of 3000 p.s.i. in accordance with the "Joint Committee Specifications for Concrete", June 1940.
Base of structure to be placed on undisturbed natural foundation or compacted backfill.
All reinforcement shall be placed so that the centers of bars in the outer layer will be 2" from face of concrete, for 1/2" or 3/4" bars and 2 1/2" for 7/8" bars or larger, unless otherwise shown.
All dimensions to reinforcement are to centers of bars.
Lap bars 20 diameters at splices, unless otherwise shown.
Chamfer all exposed edges of concrete 3/4".
Details of door, windows, control joints, and roofing for Operator's house similar to chlorination station architectural details on Dwg. 409-D-421.
REFERENCE DRAWINGS
LOCATION OF STRUCTURE 409-C-404
EXISTING STRUCTURE 409-D-415
TURNOUT AND METERING STRUCTURE-SECTIONS 409-D-415
TURNOUT AND METERING STRUCTURE-REINFORCEMENT 409-D-417, 418
MISCELLANEOUS METAL 409-D-422, 423
CHAIN LINK FENCE 409-D-411
CHLORINATION STATION-ARCH. DETAILS 409-D-421
ELEVENTH NAVAL DISTRICT - SAN DIEGO, CALIF.
SAN DIEGO AQUEDUCT PROJECT
SAN JACINTO - SAN VICENTE AQUEDUCT
SECOND PIPE LINE
SOUTH STA. 49+67
TURNOUT AND METERING STRUCTURE
GENERAL PLAN AND SECTIONS
UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION
SAN DIEGO COUNTY WATER AUTHORITY
409-D-414
DENVER, COLO., AUG. 1, 1952
569963

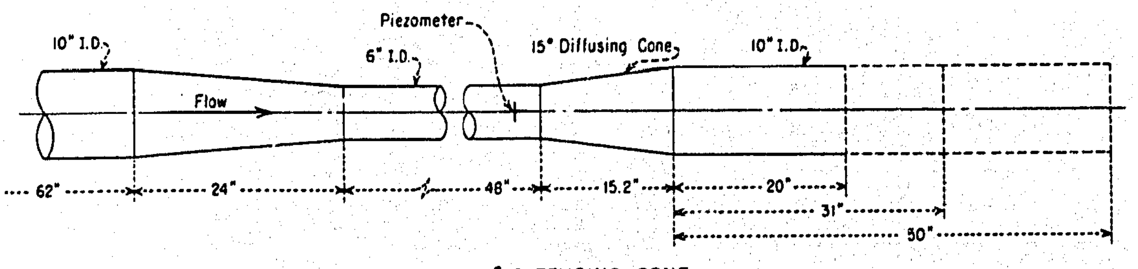
FIGURE 5
REPORT HYD. 365



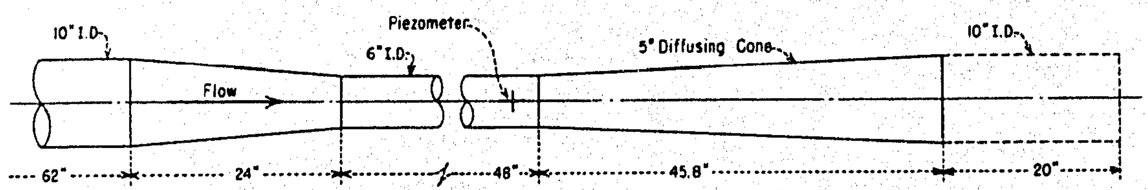


SAN DIEGO AQUEDUCT
SAN JACINTO-SAN VICENTE TURNOUT AND METERING STRUCTURE

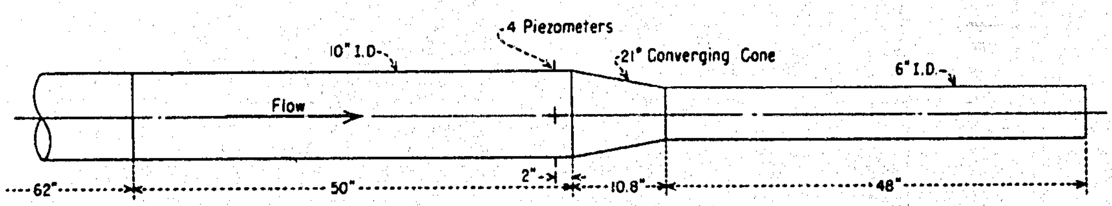
SCHEMATIC DIAGRAM OF HYDRAULIC MODEL
1:6 SCALE



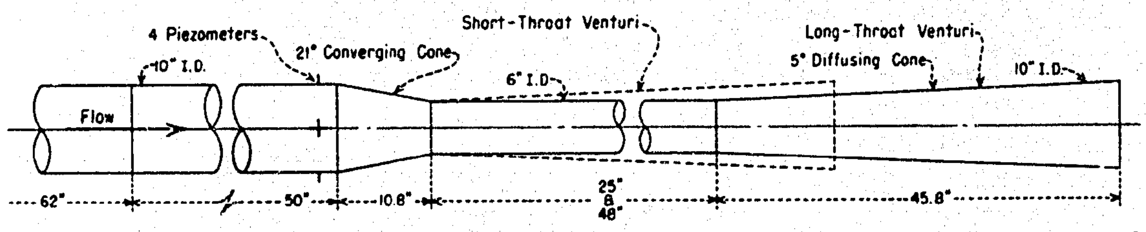
A. 15° DIFFUSING CONE



B. 5° DIFFUSING CONE

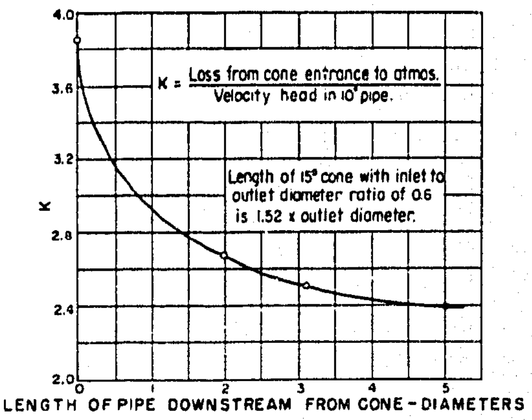


C. 21° CONVERGING CONE

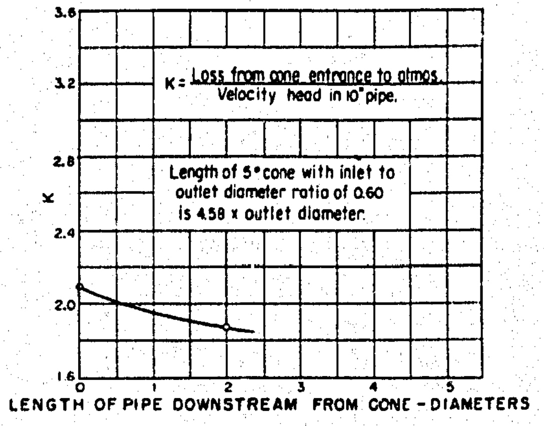


D. VENTURI METERS

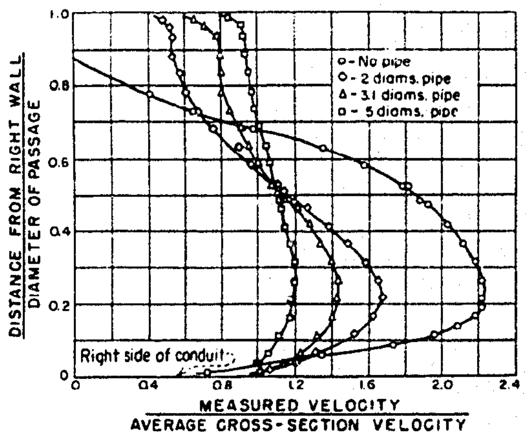
SAN DIEGO AQUEDUCT
SAN JACINTO-SAN VICENTE TURNOUT AND METERING STRUCTURE
PIPING ARRANGEMENTS FOR TESTS ON COMPONENTS
OF 60-INCH VENTURI METER
AIR MODEL - 1:6 SCALE



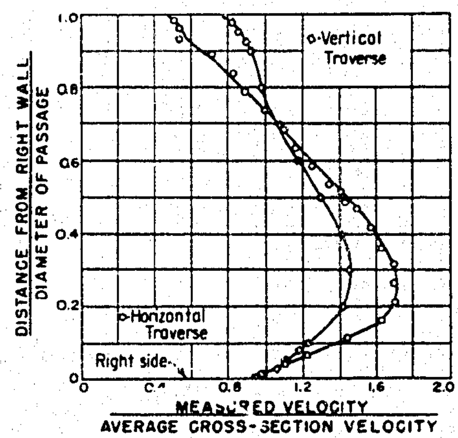
A. 15° CONE-LOSS VS. LENGTH OF PIPE DOWNSTREAM FROM CONE



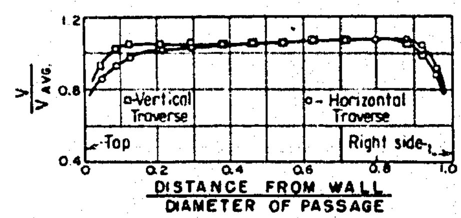
B. 5° CONE-LOSS VS. LENGTH OF PIPE DOWNSTREAM FROM CONE



C. 15° CONE-VELOCITY PROFILES AT PIPE OUTLET ALONG HORIZONTAL DIAMETER

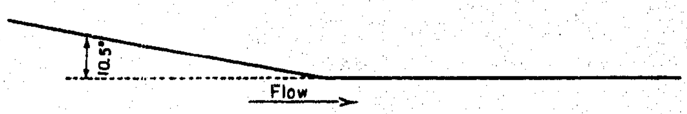


D. 5° CONE-VELOCITY PROFILES AT PIPE OUTLET

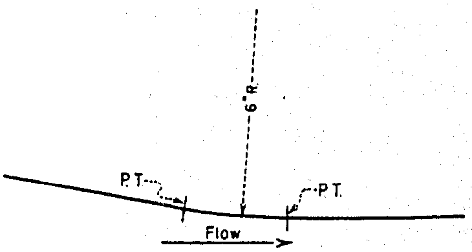


E. VELOCITY PROFILE AT CONE INLETS

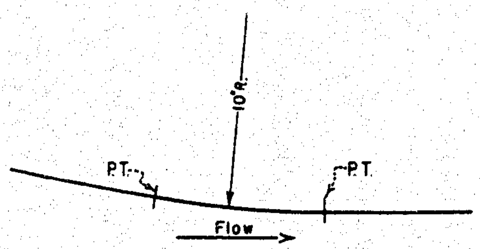
SAN DIEGO AQUEDUCT
SAN JACINTO-SAN VICENTE TURNOUT AND METERING STRUCTURE
EFFECT OF LENGTH OF PIPELINE DOWNSTREAM FROM CONICAL DIFFUSER ON LOSSES AND ON VELOCITY DISTRIBUTION
AIR MODEL - 1:6 SCALE



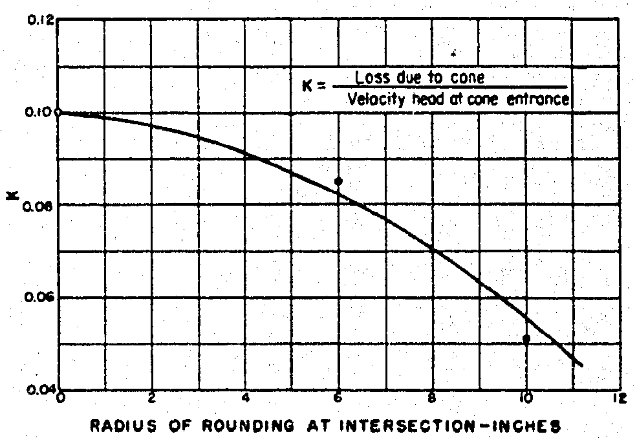
A. SHARP CORNER - ZERO RADIUS OF ROUNDING



B. 6" RADIUS OF ROUNDING

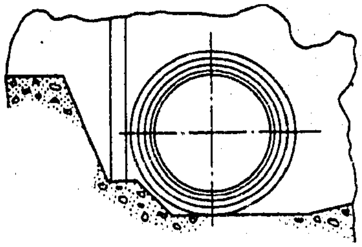


C. 10" RADIUS OF ROUNDING

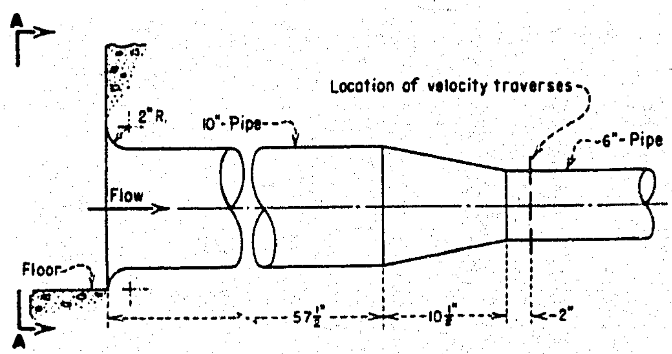


D. HEAD LOSS VS. RADIUS OF ROUNDING

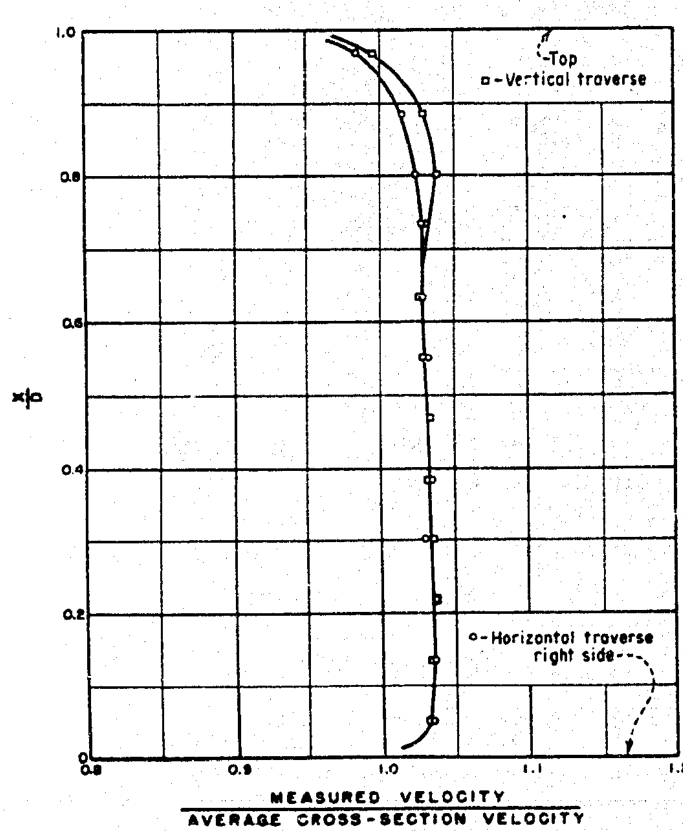
SAN DIEGO AQUEDUCT
SAN JACINTO-SAN VICENTE TURNOUT AND METERING STRUCTURE
REDUCTION IN LOSSES OBTAINED BY ROUNDING JOINT BETWEEN CONE AND STRAIGHT PIPE
AIR MODEL - 1:5 SCALE



A. SECTION A-A



B. SIDE VIEW



C. VELOCITY PROFILES

SAN DIEGO AQUEDUCT
SAN JACINTO-SAN VICENTE TURNOUT AND METERING STRUCTURE
VELOCITY PROFILE IN THROAT OF 60-INCH VENTURI METER
HYDRAULIC MODEL - 1:6 SCALE